Optimization of multilayer micro channels heat sinks cooling system using genetic algorithm

Husain Zaidan[1, a *], Robiah Ahmad[2,c] and Normah Mohd Ghazali[1b]
[1]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia: 81310, Johor Bahru, Johor, Malaysia
[2]UTM Razak School of Engineering and Adv. Techn., Universiti Teknologi Malaysia
54100 Jalan Semarak, Kuala Lumpur, Malaysia
[a]husain_zaidan2000@yahoo.com, [b]normah@fkm.utm.my,
Corresponding author: [c]robiahahmad@utm.my

***Abstract*—Cooling of electronic devices is problematic by its nature simply because of the space restriction. Recent advances in high powered miniaturized electronic systems have come at the expanse of very high heat fluxes that pose challenges to thermal management research. Uncontrolled excessive heat may cause thermal fatigue and stresses and the current micro electro-mechanical cooling systems (MEMS) which utilize the single layer micro channel heat sink, introduced a decade ago, may no longer be an adequate solution. Possible extension of the layer of parallel micro channels into a stacked system, by developing two, three, and multi-layer channel systems are being investigated. The design of all these systems depends on several parameters; coolant type, channel geometry, channel dimensions, and the number of the channels. This paper reports a new model for optimizing the thermal resistance, developed based on specific parameters of the dimensions of the channel, the wall width between the channels, and using water as a coolant at 27℃. The outcomes of the model were compared with other published studies. The results showed that the model is valid and reliable for further studies.**

Keywords—stacked; micro channel heat sinks (MCHS); optimization; thermal resistance; genetic algorithm; computational fluid dynamics (CFD).

I. INTRODUCTION

For reasons range from the necessity of saving power to the importance of preventing damage to electronic structures, the micro electromechanical systems (MEMS) have been rapidly developing in the last two decades. Researchers have different approaches on how to design MEMS. All designs, even with internal differences, have agreed on one important goal; namely, optimizing the performance of MEMS. One of the first pioneers in this field was a single layer micro channel with the aid of a silicon wafer (50 μm width and a 300 μm height) as the heat sink and water as a coolant which was able to handle heat flux of 790 W/cm^2 at 71 K [1]. Three years later, a new micro channel has fabricated, still a single layer, but with two important differences from Tuckerman-Pease's design: 1) air was used as a coolant and 2) dimensionless ratio of the fin and the channel thickness, W_{fin}/W_{ch}, in order to test the effectiveness of the channel width and the finding suggested that the thermal resistance was minimized at specific channel width [2]. Away from these two early attempts, a micro channel with a square shape was constructed rather than rectangular shape that has been used until then .The 5 cm silicon square substrate has reached heat flux of 1100 W/cm^2. Optimization was the core purpose of the research in this field [3]. Sasaki and Kishimoto [4] have optimized the channel dimensions in regard of given pressure drop in more advanced approach. An innovative design method for water cooled micro channel heat sinks in which both laminar and turbulent flow regimes were considered by [5]. Landram [6] has determined simultaneously the temperature profiles of both the coolant and the heat sink. In a parallel approach to this optimization technique, Knight et. al. [7] was able to locate the parameters for optimum design heat sinks. The multi-layer structure (known also as stacked) was primarily developed in which it was shown that the stream-wise temperature rise along the device surface was considerably reduced compared to one-layer heat sink system. The other important finding suggested that pressure drop of the two-layered heat sink was smaller than that of the one-layered heat sink which clearly indicates that the performance was much better. As the number of layers increases, the optimization process becomes very difficult to estimate using traditional mathematical techniques. Such as numerical simulation using computational fluid dynamics CFD and other similar mathematical approaches .Vafai and Zhu [8] modelled a single layer counter flow and a double layer counter flow micro channel heat sink with rectangular channels by employing the thermal resistance network. The accuracy of the prediction was verified by comparing the results obtained with those from the more comprehensive three dimensional CFD conjugate heat transfer model, and good agreements were obtained. The results by Chong et. al. [9] showed that the overall thermal resistance was related with configuration sizes of micro-channel heat sink. Wei and Joshi [10-11] developed techniques to deal with the optimization process for stacked micro channel heat sink. Square copper mini channel heat sinks were fabricated with single and multiple layers. The results were experimentally indicated that multilayer heat sinks have significant advantages over single layer equivalents with reductions in thermal resistance and pressure drop. Numerical simulations using CFD were performed and comparisons were made with experimental results [12]. Recent studies have dealt with more advanced techniques to optimize the efficiency of micro-channel cooling heat sink using the thermal resistance network model [13]-[17]. In this study, an optimization of multilayer micro channels heat sinks (MCHS) using genetic algorithms (GA) was developed to analyse on the parameters at which the performance of MCHS has its own limitation and at which the multi-layer has no effect on the outcome. The approach shows that as the flow is changing, the multi-layer performance becomes null after which a reverse optimization is taking place.

II. GENETIC ALGORITHM (GA)

Genetic algorithm (GA) is a stochastic numerical search method, inspired by process occurring in biological evolution, which was first conceived by Holland [18]. Previous studies have proven the increase in designers and researchers demands for a global optimization technique to eliminate some of the pre-requirements of the conventional optimization techniques. Prior works showed that the genetic algorithm optimization technique has been successfully implemented in multi objectives optimization cases such as the one considered in the proposed research. In recent years, applications of Genetic Algorithms (GAs) in thermal engineering have received much attention for solving real-world problem. Applications of GAs into heat exchangers optimizations have suggested that GAs have a strong ability of search and combined optimization and can successfully optimize and predict thermal problems. Thus applications of GAs in the field of thermal engineering are new challenges. At this point, the ability of GAs to search difference region of solution space make it possible to find a diverse set of solution. By using GAs, there are more than variables can be optimizing at one time. an optimization model for cylindrical pin-fin heat sink using genetic algorithms as an optimization technique, Entropy generation rate due to heat transfer and pressure drop across pin-fin was minimized using genetic algorithms, they surmised that genetic algorithms is a very suitable optimization technique for the optimization of pin-fin heat sinks involving several variables which could produce a high quality solution, [19]. Najafi and Najafi [20], successfully utilized multi-objective optimization using genetic algorithms in order to achieve optimal design parameters for plate and frame heat exchangers.

III. THERMAL RESISTANCE MODEL

The micro channel heat sink's thermal performance can effectively be described by its total thermal resistance. To analyse the performance of the heat sink, the modelling is described by a network of resistances connected in series, parallel, and combination. Fig. 1 shows the schematic of multilayer micro channel in which the lower part could represent a single layer. The micro-channel has rectangular cross section of height H_c and width w_c and separated by w_w from the neighbouring channel. These parameters are related to each other by aspects ratios; namely, $\alpha = H_c/w_c$ and $\beta = w_w/w_c$. The heat sink which is consisted of many channels has width W, length L and height H. The computational zone which represents a half channel is shown in Fig. 2. The total resistance of the single layer micro channels heat sink is shown in Fig. 3 can be expressed by the following formula in (1) and (2),

$$R_{single} = R_{base} + R_f + [(R_{wall} + R_d) \| (R_a + R_o)] \quad (1)$$

$$R_{single} = R_{base} + R_f + \frac{(R_{wall}+R_d)(R_a+R_o)}{R_{wall}+R_d+R_a+R_o} \quad (2)$$

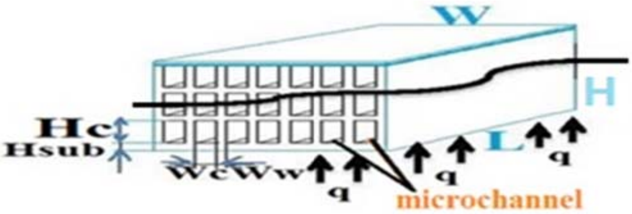

Fig. 1. Schematic of the stacked (multilayer) rectangular micro-channel heat sink.

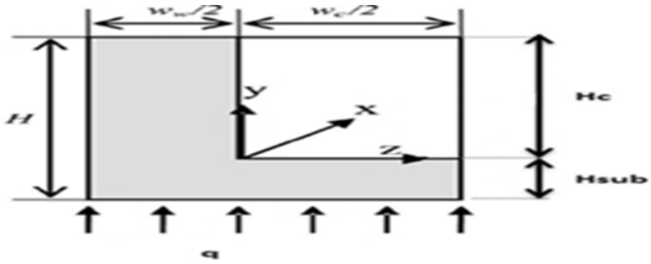

Fig. 2 Schematic diagram of computational zone cross-section

The thermal resistance of the single layer is modelled as shown in Fig. 3.

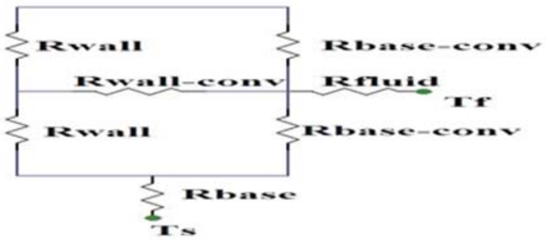

Fig. 3 Single layer heat sink thermal resistance network

The resistance network for the repeated single layer (stacked) of "n" layers is shown in Fig. 4.

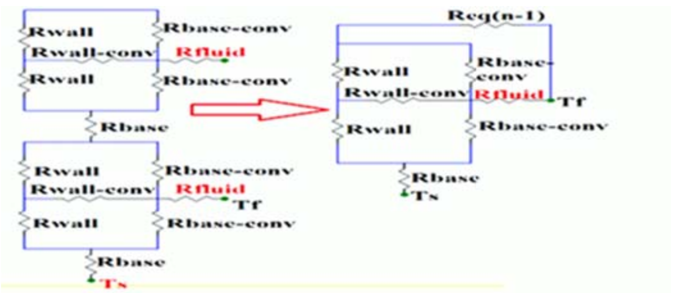

Fig. 4 Multi–layer heat sink: thermal resistance network for n layers.

Since the thermal resistance network for "n", layers shown in Fig. 4 consists of series and parallel resistance network, the total thermal resistance of the network can be calculated using delta-wye transformation shown in Fig. 5.

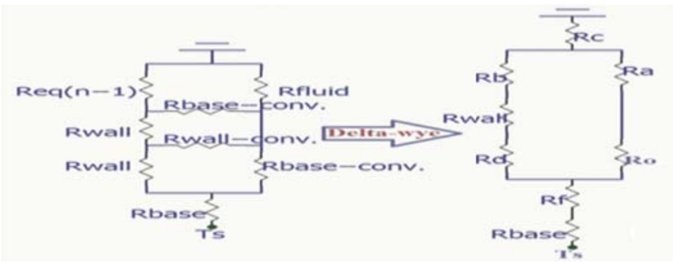

Fig. 5 delta-wye transformation

For multilayer MCHS, the fitness function is the equivalent resistance "R_{total}" is expressed in (3),

$$R_{total} = R_c + R_f + R_{base} + \frac{(R_b+R_{wall}+R_d)(R_a+R_o)}{R_b+R_{wall}+R_d+R_a+R_o} \tag{3}$$

In this study, the width and the length of the sink are 30cm x 30cm.The thickness of the base of the micro channel $H_{sub} = 100\,\mu m$ and the depth of the micro-channel$H_c = 500\,\mu m$, both are kept constant. The aspect ratio $\alpha = H_c/\,w_c$ and the spacing ratio $\beta = w_w/w_c$ are optimized as variables x_1 and x_2 in the simulation, respectively with different number of layers ($n = 1$ to 5) of the stacked micro-channel to investigate the effect on the minimized thermal resistance at different flow rate $G = 0.1, 0.3, 0.5, 1.0$ *and* $1.5\,x10^{-6}$ m^3/s. Bases on the above condition the model limitation were defined.

In this optimization, the genetic algorithms (GAs) were utilized to optimize the total thermal resistance. The coolant fluid used in this study is water at 27°C. All physical and engineering parameters for water were taken as follow: density ρ= 997 kg/m^3, specific heat c_p = 4179 J/Kg°C, and dynamic viscosity μ = 8.55x10^{-4} kg/m s. The heat sink was made of silicon with thermal conductivity of k_{si} = 148 W/m°C.the necessary dimensions and thermophysical properties required in optimization process are listed in Table 1.

TABLE 1.Required dimensions and properties for the optimization Process

Dimensions and properties	Values
Heat sink length ,L (m)	3x10^{-1}
Heat sink width ,W (m)	3x10^{-1}
Microchannel height, H_c (m)	5x10^{-4}
Material thermal conductivity (Si), k_{si}(W/m°C)	148
Coolant thermal conductivity (water), k_w (W/m°C)	0.613
Density of the coolant , ρ (kg/m^3)	997
Dynamic viscosity of the coolant , μ (kg/m s)	8.55x10^{-4}
Flow rate, G (m^3/s)	0.1, 0.3 , 0.5, 1.0 and 1.5x10^{-6}
Specific heat of the coolant, c_p (J/Kg°C)	4179
Number of layer	1-5
Thickness of the substrate, H_{sub} (m)	1x10^{-4}
physical and engineering parameters for water , °C	27

The Genetic Algorithms Toolbooks is a collection of routine, written mostly in m-files, which implement the most important functions in genetic algorithms. The main data structures in the Genetic Algorithms Toolbooks are chromosomes, objective function values and fitness values. The genetic algorithms uses three main types of rules at each step to create the next generation from the current population, selection rules select the individuals called parents that contribute to the population at the next generation, Crossover rules combine two parents to form children for the next generation and Mutation rules apply random changes to individual parents to form children. The flow chart of the Genetic Algorithms shown in Fig.6 and the Genetic Algorithms Parameters are given in Table 2.

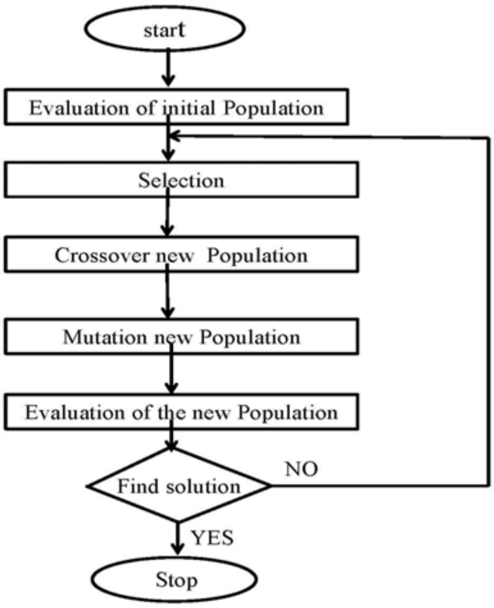

Fig.6 Flow chart Genetic Algorithms.

Table 2.Genetic Algorithm Parameters

Parameters	Values
Fitness function	@multilayer
Number of variables	2
Population type	Double vector
Population size	20
Creation function	uniform
Selection function	Stochastic uniform
Crossover fraction	0.8
Crossover function	scattered

IV. RESULTS AND DISCUSSION

The flow rate G of $0.1, 0.3, 0.5, 1.0$, and 1.5x10^{-6} m^3/s were considered to optimize the overall thermal resistance, R [°C/W] of layers $n = 1$ to 5 at constant $\alpha = H_c/\, w_c =$ 0.5, $\beta = w_w/w_c = 1.0$, height of the channel $H_c =$ 500 [μm], and the width of the substrate $H_{sub} = 100$ [μm].The optimization process was performed using genetic algorithms (GAs) of MATLAB R2012b .The genetic algorithms toolbox uses MATLAB matrix functions to build as set of versatile tools for implementing a wide range of genetic algorithms methods..

The optimization was designed for two purposes - to test the reliability of the model and to valid the proposed model of multi-layer micro channels heat sink which was developed in conjunction with the method network of resistances connected in parallel, series and combination with the experimental results by [12]. During the optimization process, the parameters are kept constant except the flow rate, G. In this study, the thermal resistance R_{total} is minimized based on the proposed mathematical model using genetic algorithm. With the optimized thermal resistance R_{total}, the related parameters such as Reynolds's number R_e, pressure drop, pumping rate, geometrical and dimensions of the channel are also evaluated.

Fig. 7 shows the overall optimized thermal resistance, R, with the number of layers, $n = 1$ to 5. At the lowest flow rate of 0.10x10^{-6} m^3/s, R is the highest; about 2.5 °C/W. As the number of layers increases, R decreases to about 0.7 °C/W or, in percentage wise, it decreases to about 28% of its highest value at single layer. As the flow rate increase to 0.3x10^{-6} m^3/s, the trend of decreasing R is same as in previous result, however the percentage decrease in R is slightly higher than the it's percentage of $G = 0.10$x10^{-6} m^3/s. The trend of decreasing R with increasing layers continues for higher flow rates but the percentage decrease of R at, for instance, flow rate of 1.50x10^{-6} m^3/s is very close to 100% which means that there is virtually no effect to the multi-layer foundation for the heat sink. "Fig. 8" also shows that increasing the flow from 0.10 to 1.5x10^{-}6 m^3/s will decrease R for and multi-layer MCHS; however the decrease in R becomes less as the number of layer increases. The results presented here are in agreement with the findings of the experimental work performed by [12]. These results are plotted in Fig. 8, which clearly shows the variation of R as a function of number of layers. The results in Fig. 8 show that the highest R for the same number of layer is decreasing as the flow rate increases.

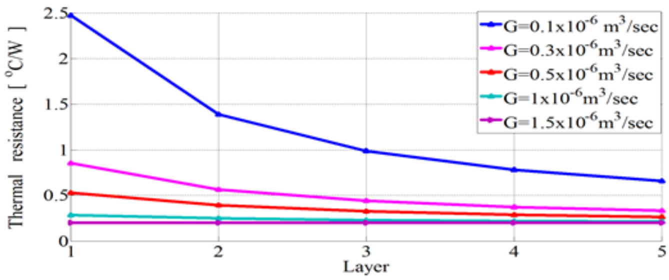

Fig. 7 Thermal Resistance with n Layers

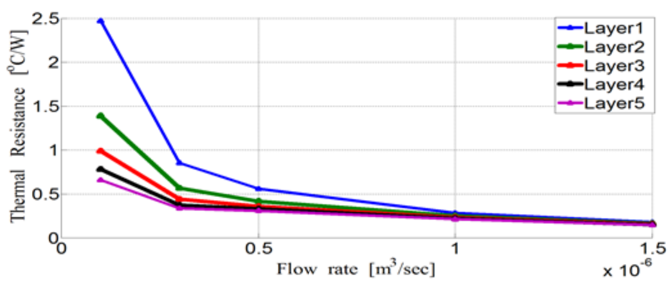

Fig. 8 Flow Rate with Thermal Resistance

In another simulation study, the relationship of the overall optimized thermal resistance, R, °C/W and pumping power, P, 10^{-4} W are conducted. It is important to note that the pumping power is the power required to provide the heat sink with specific flow. Fig. 9, shows that the as the pumping power, P, increases, R rapidly decreases and becomes almost constant as the R reaches the lowest value of 0.2 °C/W. These results are in agreement with experimental study in [12].

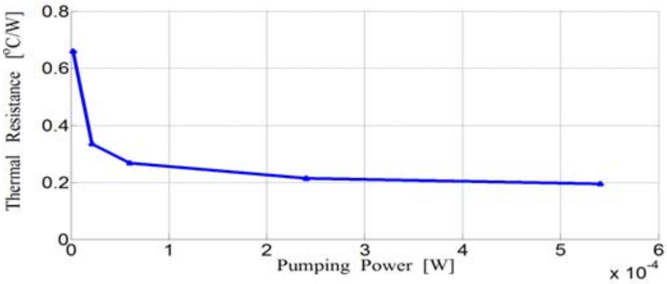

Fig. 9 Variation of pumping power with overall thermal resistance optimized for stacked layer heat sinks.

The optimization goes further to show how the overall optimized resistance,R, behaves with the flow rate, G "Fig. 10'', shows that as R decreases from about 0.7 °C/W to 0.2°C/W, the flow rate increases from 0.1 to $1.5 x 10^{6}$ m^3/s. This trend is in agreement with results by Tuckerman and Pease's [1] and Lei [12].

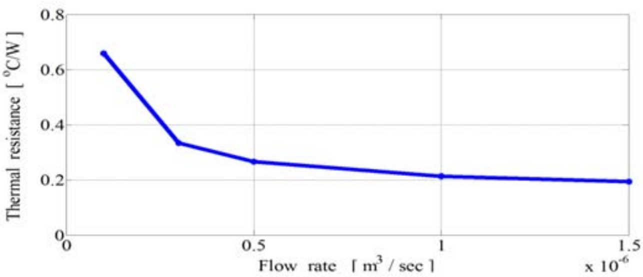

Fig. 10 Flow Rate with Thermal Resistance

Figs 9 and 10 show similarity for the relationship between the flow rate and the pumping power to thermal resistance which are is positively related.

To complete the cycle, it is also important to study on the relationship of Reynolds' number, Re= $\frac{\rho v D}{\mu}$, and friction factor, f, and Fig. 11 shows that as Re increases from about 10 to 160, both laminar, the flow velocity increases since the density of water, ρ, the diameter of the hydraulic diameter of the channel, D, and the dynamic viscosity, μ are constants. When the velocity of the flow increases, more power and pressure loss is expected.

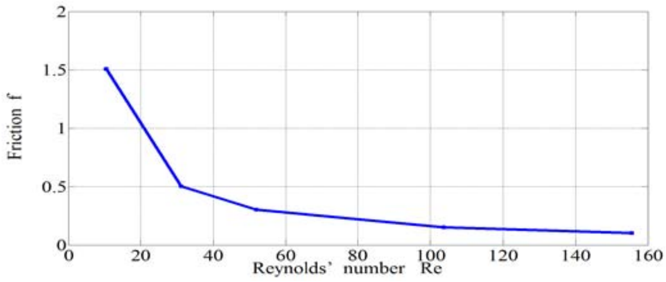

Fig. 11 Reynolds' number Re with friction factor f

V. CONCLUSION

The proposed model for the heat sink has been aligned with the results proposed by several previous studies. The results are in agreement with the experimental studies done by Lei, [12] on the overall optimized thermal resistance and how the number of layers affects the parameters in the structure such as the flow rate, pumping power, and the pressure drop. The results shown in Fig. 7 to 11 were determined at specific control (restriction) imposed on some parameters such as the ratios α and β. Based on the results, the multi-layer micro channel heat sink could be used as the alternative to the traditional cooling system which requires high power – the factor that affects the environment. The heat sink which is presented in this study could be developed where the overall optimized resistance approaching zero through which the power needed is negligible. We have shown in this study a genetic algorithms (GAs) optimization procedure that offers very good solutions for optimum thermal resistance. This study is introductory and it is aimed to test the validity of the parameters included in the model and prove its reliability. However, more studies are on the way in order to explore the best parameters which serve the environment and to depict the need to fulfil some of the challenges that are facing today's engineers and for the rest of this century.

Acknowledgment

The authors would like to gratefully acknowledge the financial supports from Ministry of Higher Education (MOHE) Malaysia and Universiti Teknologi Malaysia (UTM) under the VOT RUGS 04H55.

REFERENCES

[1] D. B. Tuckerman and R.F.W. Pease, "High-performance heat sinking for VLSI", *IEEE Electron Device Letters*, Vol. EDL-2 No. 5, pp. 126-129, 1981.

[2] N. Goldberg, "Narrow channel forced air heat sink", *IEEE Trans. Comp. Hybrids Manuf. Technol*., vol. CHMT-7, pp. 154-159, Mar. 1984.

[3] M. Mahalingam, ''Thermal management in semiconductor device packages", Proc. *IEEE*, vol. 73, pp. 1396-1404, Sept. 1985.

[4] S. Sasaki and T. Kishimoto,"Optimal structure for micro-grooved cooling fin for high-power LSI devices," Electron. Lett. vol. 22, no.25, pp. 1332-1334, 1986 .

[5] R. J. Phillips. ''Micro-channel heat sinks'', Advances in Thermal Modelling of Electronic Components and Systems, Volume 2. A. Bar-Cohen and A. D. Kraus, eds. New York: ASME, Ch. 3, 1990.

[6] C. S. Landram, "Computational model for optimizing longitudinal fin heat transfer in laminar internal flows," Heat Transfer in Electron Equipment, vol. 171, pp. 127-134, 1991

[7] R. W. Knight, J. S. Gooding and D. J. Hall, " Optimal thermal design of forced convection heat sinks - analytical", Journal of Electronic Packaging, Vol. 113, No.3, pp 313-321, 1991.

[8] K. Vafai and L. Zhu, "Analysis of two-layered micro-channel heat sink concept in electronic cooling", International Journal of Heat and Mass Transfer, 42, pp.2287-2297, 1999 .

[9] S. H. Chong, K. T. Ooi and T. N. Wong "Optimisation of single and double layer counter flow microchannel heat sinks", Applied Thermal Engineering 22 ,pp1569–1585, 2002.

[10] X. J .Wei and Y. Joshi, "Stacked Micro channel Heat Sinks for Liquid Cooling of Microelectronic Components" Journal of Electronic Packaging, Transactions of the ASME, Vol. 126, March 2004.

[11] X. J .Wei and Y. Joshi, "Optimization Study of Stacked Micro-Channel Heat Sinks for Micro-Electronic Cooling", IEEE Trans. on Compon. And Pack. Tech., Vol. 26, No. 1, March 2003.

[12] N. Lei, P. Skandakumaran and A. Ortega ,**"** Experiments and Modeling of Multilayer Copper Minichannel Heat Sinks in Single-Phase Flow**",** *IEEE*, pp. 9-18, 2006.

[13] B. D. Shao, Z. W. Sun and, L. F. Wang, ''Optimization design of micro channel cooling heat sink'', International Journal of Numerical Methods for Heat & Fluid Flow, Vol. 17 No. 6, pp. 628-37, 2007 .

[14] B. D. Shao, L. F. Wang, Li. J.Y. and Z.W. Sun, "Application of thermal resistance network model in optimization design of micro-channel cooling heat sink", International Journal of Numerical Methods for Heat Fluid Flow, Vol. 19 No. 3, pp. 535–45.2009 .

[15] B. D. Shao, L. F. Wang, Li. J.Y. and H. M. Cheng, "Optimization and Numerical Simulation of Multi-layer Micro channel Heat Sink", Procedia Engineering 31, pp928 –933,2012 .

[16] B. D. Shao, L. F. Wang, Li. J. Y. and H. M. Cheng, "Multi-objective optimization design of multi-layer rectangle micro-channel heat sink for single-phase flow and heat transfer", Advance Materials Research Vol.709, pp286-291. 2013.

[17] M. L. Levac, H. M. Soliman and S. J Ormiston,"Three-dimensional analysis of fluid flow and heat transfer in single- and two-layered micro-channel heat sinks", Heat and Mass Transfer, Vol. 47 No. 11, pp. 1375-83.2011.

[18] J. Holland, ''Adaptation in Natural and Artificial System'', University of Michigan Press, Ann Arbor, MI, 1975.

[19] S. Mohsin, A. Maqbool and W.A .Khan, ''Optimization of cylindrical pin-fin heat sink using genetic algorithms''. *IEEE Transaction on Components and Packaging Technology*, 32, (1), pp.44-52, 2009.

[20] H. Najafi, B. Najafi , ''Multi-objective optimization of a plate and frame heat exchanger via genetic algorithm'', Heat and Mass Transfer Volume 46, (6), pp. 639-647, 2010.